

## The Effects of Silver Coating on Friction Coefficient and Shear Bond Strength of Steel Orthodontic Brackets

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**Summary:** Aims of the present study was to measure frictional resistance between silver coated brackets and different types of arch wires, and shear bond strength of these brackets to the tooth. In an experimental clinical research 28 orthodontic brackets (standard, 22 slots) were coated with silver ions using electroplate method. Six brackets (coated: 3, uncoated: 3) were evaluated with Scanning Electron Microscopy and Atomic Force Microscopy. The amount of friction in 15 coated brackets was measured with three different kinds of arch wires (0.019 × 0.025-in stainless steel [SS], 0.018-in stainless steel [SS], 0.018-in Nickel-Titanium [Ni-Ti]) and compared with 15 uncoated steel brackets. In addition, shear bond strength values were compared between 10 brackets with silver coating and 10 regular brackets. Universal testing machine was used to measure shear bond strength and the amount of friction between the wires and brackets. SPSS 18 was used for data analysis with *t*-test. SEM and AFM results showed deposition of a uniform layer of silver, measuring 8–10 μm in thickness on bracket surfaces. Silver coating led to higher frictional forces in all the three types of arch wires, which was statistically significant in 0.019 × 0.025-in SS and 0.018-in Ni-Ti, but it did not change the shear bond strength significantly. Silver coating with electroplating method did not affect the bond strength of the bracket to enamel; in addition, it was not an effective method for decreasing

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**Key words:** Dentistry, Friction, Metal Coatings, Sliding, Steel brackets

### Introduction

Orthodontic treatments are associated with tooth movements. One of the common techniques in this field is sliding the tooth on wires, which has advantages such as a decrease in clinical treatment time, patient comfort, and control of tooth movement in three dimensions. However, one of the important problems of this method is friction between the wire and bracket (Shames, '96).

Silver metal or ions have been known historically for their potent antibacterial effects (Kang *et al.*, 2000). Materials containing silver are chemically stable and release silver ions for a long period (Toshikazu, '99). Long-lasting antimicrobial effects, temperature stability, and low volatility of silver particles are some of the facts that promoted renewed interest in use of silver particles as antimicrobial agents (Kumar and Munstedt, 2005). The growing numbers of antibiotic-resistant bacterial strains are less likely to develop resistance against silver particles (Pal *et al.*, 2007; Stobie *et al.*, 2008). The antibacterial effect of silver has been shown against gram-positive bacteria, gram-negative bacteria, fungi, protozoa, and particular viruses in an extended spectrum (Monteiro *et al.*, 2009; Ryu *et al.*, 2011; Morita *et al.*, 2014). Radial diffusion test method has shown promising antibacterial results of silver coating of orthodontic wires against different bacterial strains (Morita *et al.*, 2014).

There are different methods to deposit and form thin layers of silver in medicine and dentistry, such as physical vapor deposition (PVD; Ryu *et al.*, 2011), sol/gel method

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TABLE I Coefficient of friction

Material pair	Friction coefficient
Stainless vs. stainless	0.80
Titanium vs. titanium	1.00
Hardened steel vs. itself	0.35
Cadmium plate vs. steel	0.20
Silver vs. stainless or Ti	0.18

(Jeon *et al.*, 2003), and electroplating (Guo *et al.*, 2012). Electroplating is the application of a metal coating to a metallic surface by an electrochemical process. This coating is produced by using the material to be coated as a cathode immersed in a silver salt in an electrolytic cell (Guo *et al.*, 2012).

On the other hand, the role of silver coatings has been shown in decreasing friction at high temperatures. Silver has the least amount of contact resistance among metals. Coefficient of friction between silver and stainless steel (SS) is lower than between two stainless steel metals (Sloney '86; see Table I). Therefore, in this study silver has been used to cover the surface of brackets.

Friction is an important factor in controlling orthodontic anchorage, especially in space closure with fixed appliances. When the teeth slide along arch wire, the force is necessary for two main reasons; first to overcome frictional resistance and the second for bone remodeling and subsequent tooth movement. Unfortunately, the effect of both forces (friction and the force of tooth movement) is transferred to anchorage teeth (Proffit, 2007). In addition, the combined forces will increase the risk of root resorption (Thorstenson and Kusy, 2001). Therefore, controlling and decreasing frictional forces is an important aspect of the control of anchorage.

Factors affecting the friction of orthodontic appliances are the quality of the surfaces of brackets and wires, and the contact forces (Proffit, 2007). Although the amount of friction in metal brackets is one-third of that in ceramic brackets (Guerrero *et al.*, 2010), extensive studies have been carried out to improve the surface properties of wires, and metal brackets, for example covering the surface of brackets with different materials like diamond-shaped carbon, Teflon, Titanium nitride, etc (Kao *et al.*, 2011; Farronato *et al.*, 2012; Murguruma *et al.*, 2013).

Coating of brackets can create microscopic changes in the structure of the bracket base that might affect the bond between the bracket and tooth; such changes were surveyed in the present study too.

## Materials and Methods

### Electroplating

In this experimental study, a total of 56 standard 22 slot brackets (American, USA) were used which 28 has

been silver coated by an electroplating process. Electroplating is a process that uses electric current to reduce dissolved metal cations so that they form a coherent and uniform coating on an electrode. All the specimen surfaces were polished by barrel polishing and cleaned sonically with alcohol for 15 min. Then the cleaned brackets were coated by an electroplating process. Stainless Steel brackets conduct electricity therefore it easily coated using electroplating method. The silver galvanic deposition technique by electrochemical reactions had occurred. The electrolyte (supplier of silver ions) that was used in this process includes Silver nitrate, Sodium phosphate, and Ammonium phosphate. After the preparation of the electrolyte solution, pH was approximately 8.5. Silver ions that are positively charged (the anode) moved into the electrolyte solution and over time precipitated on to the negatively charged bracket surfaces (the cathode).

### Surface Morphologies and Atomic Composition

The surface morphology of the specimens at nearest possible area to the slots was examined by scanning electron microscopy (SEM, KYKY-EM3200, China) and the atomic composition was monitored by atomic force microscopy (AFM, FlexAFM, Switzerland) technology before and after electroplating. Three silver coated and three uncoated brackets were scanned using an area size of approximately  $10\ \mu\text{m} \times 10\ \mu\text{m}$ .

### Friction Measurement

A total of 15 coated and 15 uncoated standard 22 slot brackets (American, USA) and 30 branches of straight wires (Dentaram, Germany) were divided into 6 groups, each containing 5 brackets:

1. Coated brackets and  $0.019 \times 0.025$ -in SS wire
2. Uncoated brackets and  $0.019 \times 0.025$ -in SS wire
3. Coated brackets and 0.018-in SS wire
4. Uncoated brackets and 0.018-in SS wire
5. Coated brackets and 0.018-in Ni-Ti wire
6. Uncoated brackets and 0.018-in Ni-Ti wire

For measuring the friction between the wire and bracket, a special apparatus was constructed to ensure zero angles of the wires when moving through the bracket slots and was fixed to the lower stable plate of a universal testing machine (SANTAM-, Sahand Company, Iran) so that their slot was precisely parallel to the edge of the plate. This machine uses straight-line static traction test to simulate sliding of wire in the bracket. Then artificial saliva was sprayed on them. The wire was attached to the bracket using elastic ligation; the upper end of the wire was attached to the upper plate of testing

machine; and the wire was pulled out with a 50-N load at a rate of 2 mm/min. Friction force was recorded by the highest point reached when the wires moved through the bracket slots. Data relating to changes in the force and displacement were stored in the computer software. Independent 2-sample *t*-test was used for statistical analysis (IBM SPSS ver. 18).

### Shear Bond Strength Test

Twenty human premolar teeth were stored in distilled water at room temperature, at 0.2% thymol to inhibit bacterial growth (0.2%). Previously restored teeth or teeth with enamel defects or cracks (observed at a magnification of  $\times 10$ ) were excluded. The teeth were divided randomly into two groups: group One: 10 coated brackets and group two: 10 uncoated brackets. After a 15 sec polish with fluoride and oil-free pumice by using a rubber prophy cup and a slow-speed hand piece, the buccal crown surface of each tooth was rinsed, and dried.

Coated and uncoated brackets (American Orthodontics) were bonded to the teeth with Transbond XT (Unitek/3M, St Paul, Minn.). The average surface of the orthodontic bracket base used was  $11.85 \text{ mm}^2$  (Samorodnitzky Naveh *et al.*, 2008). The same operator bonded all the brackets. The bonding adhesives were all light-cured with a light-curing unit (Ortholux XT, 3M/Unitek Co, St Paul, Minn) calibrated for 450 nm to ensure intensity-consistent light.

The buccal enamel surface was etched with 37% phosphoric acid for 30 sec, rinsed for 15 sec, and dried with oil- and moisture-free air until the enamel had a faintly white appearance. Transbond XT (3M-USA) primer was applied in a thin film to the etched surface and light-cured for 10 sec. Transbond XT adhesive paste was applied to the bracket base, and the bracket was positioned 4 mm apical to the cusp tip on the mid-buccal surface of tooth and pressed firmly with an instrument to expel the excess adhesive. Each bracket was subjected to a 250 g compressive force using a force gauge (Tension and Compression Gauge, Dentaureum, Germany) for 10 sec, after which excess bonding resin was removed using a sharp scaler. Then, the adhesive was light-cured for 20 sec from the mesial and 20 sec from the distal aspect of the bracket. The same operator bonded all the brackets.

Each tooth was mounted vertically in a self-curing acrylic block with a diameter of 17 mm and a height of 25 mm so that the crown was exposed. The bracketed teeth were immersed in sealed containers of distilled water and placed at room temperature for adequate water absorption and equilibration.

The samples were thermocycled (Nemo Industrial, Iran) in water at  $5 \pm 2/55 \pm 2^\circ\text{C}$  for 500 cycles. Twenty-four hours after thermocycling, shear bond strength of brackets was measured by a universal testing machine

(Universal Testing Machine, Hounsfield Test Equipment, H5K Model, England) at a crosshead speed of 0.5 mm/min. A chisel-edge plunger was mounted on the movable crosshead of the testing machine and positioned so that the leading edge aimed at the enamel–composite interface before being brought into contact at a crosshead speed of 0.5 mm per minute. The peak force levels, automatically recorded on the testing machine, were converted to stress per unit area (Mpa) by dividing the force (N) by the mean unit area of the base of the bracket ( $11.85 \text{ mm}^2$ ). T-test was used to compare the shear bond strength between the groups and  $p < 0.05$  was considered significant.

## Results

### Surface Morphologies and Atomic Composition

SEM and AFM examined the surface morphology of the specimens. SEM findings showed that the Ag coatings had a uniform thickness of about 8–10  $\mu\text{m}$  (Figures 1–3). Figures 1 and 2 show scanning electron micrographs of the surface of the brackets before and after coating. Before coating, there are some pores on the surface bracket, but after coating, the surface of the bracket is smooth, and without any pores.

Figures 4 and 5 show the representative AFM topography images ( $10 \mu\text{m} \times 10 \mu\text{m}$ ) of the outer nearest area to the slot of the orthodontic brackets before and after coating. The AFM analysis revealed that the coatings were uniform and homogeneous with an average particle size of about 370 nm and a slight surface roughness with a mean of 181 nm.

### Friction Test

Silver coating resulted in higher frictional forces in all the three types of arch wires, which was statistically

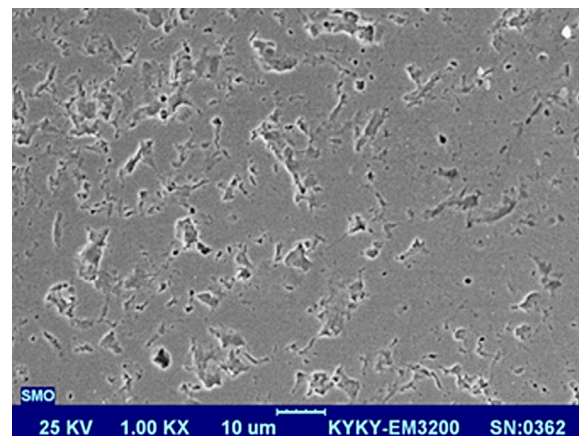


Fig 1. Bracket surface before coating at a magnification of  $\times 100$ .

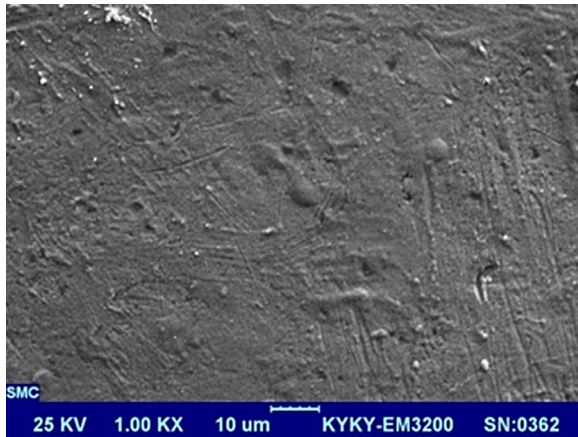


Fig 2. Bracket surface after coating at a magnification of  $\times 100$ .

significant in 0.019  $\times$  0.025-in SS, and 0.018-in Ni-Ti (Table II).

### Shear Bond Strength Test

Silver coating did not change the shear bond strength significantly (Table III).

### Discussion

In the present study, silver was used to coat brackets because of its antibacterial effects and tribological characteristics. Three types of orthodontic arch wires (0.018-in Ni-Ti, 0.018-in SS, and 0.019 $\times$ 0.025-in SS) were used for evaluation of friction to have a more accurate assessment. It was suspected that friction would decrease due to tribological characteristics of the silver but the results showed higher frictional forces in all the three types of arch wires, which was statistically significant in 0.019  $\times$  0.025-in SS and 0.018-in Ni-Ti.

In the previous studies, other materials were used for coating, such as WS2 nano-particles on SS arch wires

(Samorodnitzky Naveh *et al.*,2008), Carbon nanonitride (CNx) on SS arch wires (Wei *et al.*,2010), DLC (diamond-like carbon) on arch wires (Kao *et al.*,2011), Teflon coating on arch wire (Farronato *et al.*,2012), and Titanium nitride (Tin) coating on metal brackets (Muguruma *et al.*,2013).

In all these studies, friction between the wire and bracket decreased significantly after coating, excepting in Kao's study (Muguruma *et al.*,2013). Comparison of these results with the present study is hard because of different materials used in these studies.

The surface roughness of dental material is critical in orthodontics since it determines the contact area and influences the sliding mechanics and biocompatibility of the material (Lee *et al.*, 2010). Many in vitro studies concerning this issue have shown that friction increases with increased roughness of the wire and bracket surfaces. However, they have mainly focused on the mechanical properties of arch wires, not the changes resulting from an intraoral exposure (Marques *et al.*,2010). Since the determination of the roughness value depends on the measurement technique, the investigation protocol for surface roughness is important. The evaluation of roughness using SEM is unreliable and subjective, and the profilometer method for the quantitative analysis of roughness may induce misinterpretation due to pores on the surface. Therefore, AFM is recommended for the quantitative analysis of surfaces with nano-scale irregularities (Lee *et al.*, 2010).

The coating method in this study was electroplating while other studies have used different procedures such as plasma-based ion implantation/deposition, electrodeless, ion beam-assisted deposition, and atomizing. The thicker coating layer in this study (8–10  $\mu$ m) which produced by electroplating procedure might affected the friction results. Maybe this thick layer increased the friction by decreasing the size of the bracket slot.

On the other hand, the surface roughness of brackets increased from 70 nm to 110 nm. This might be another contributing for high friction results in the present study. It is evident that decreasing coating layer thickness would probably decrease friction.

Another problem that could rise from the coating of brackets with electroplating is alteration in microscopical structure of the bracket base, which could cause some changes in the bond between the bracket and tooth. None of the previous studies have evaluated this problem. Shear bond strength was used to this potential problem in the present study. The favorable bond strength to the enamel surface was 18–24 Mpa.

The results showed no statistically significant differences between coated and uncoated brackets in shear bond strength. It was suggested that due to lower contact resistance of silver with stainless steel and antibacterial effects, physical vapor deposition method be utilized for nanometric coating of silver on bracket so that a proper

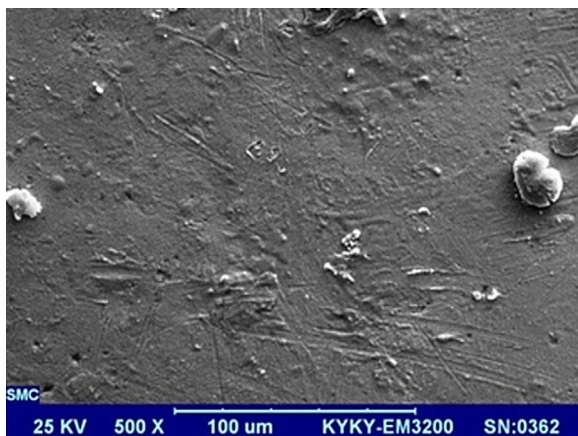


Fig 3. Bracket surface after coating at a magnification of  $\times 500$ .



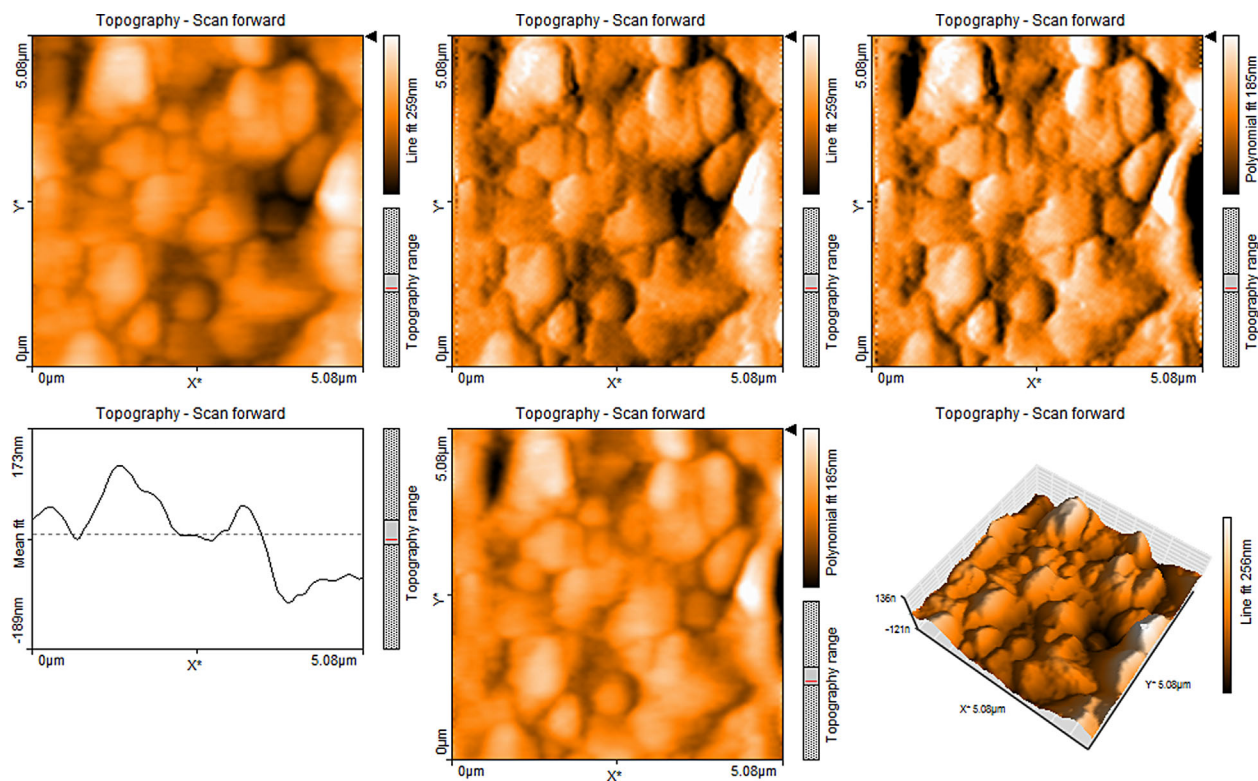


Fig 4. AFM of bracket surface before coating.

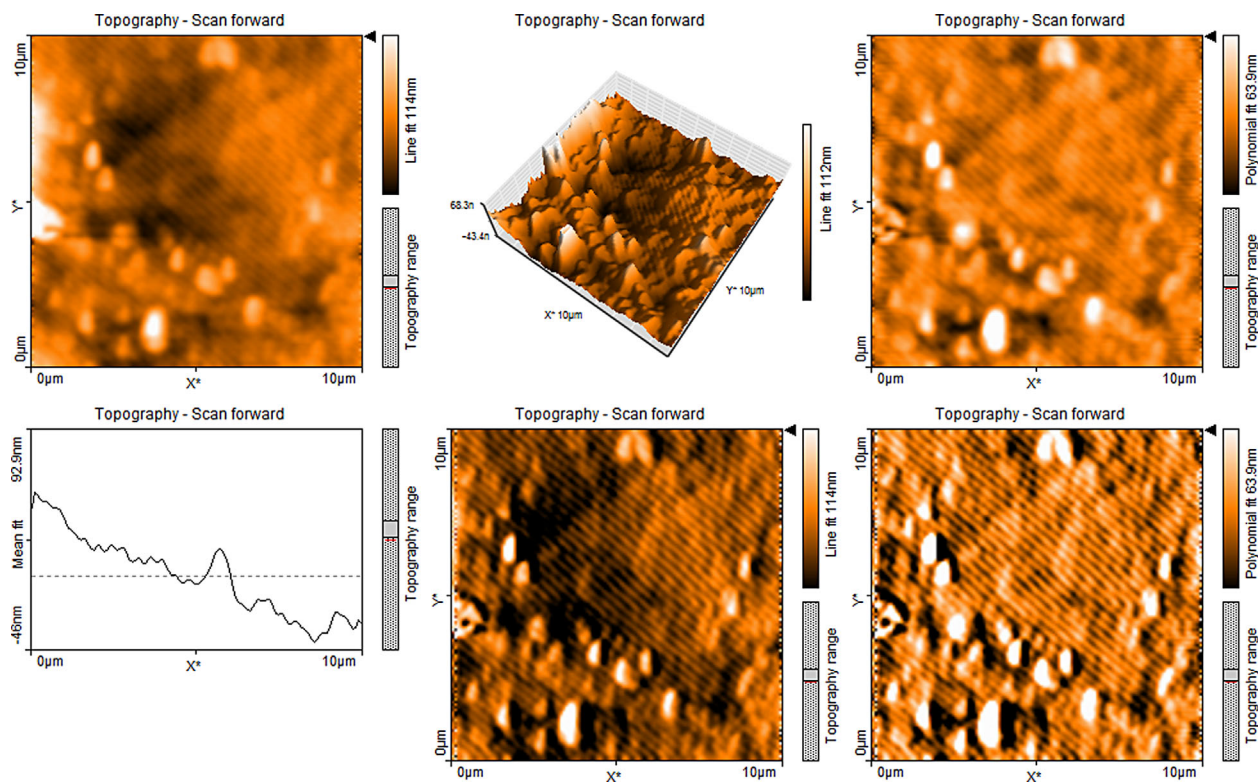


Fig 5. AFM of bracket surface after coating.

TABLE II Results of friction test

Group	Friction force (N)	Max (N)	Min(N)	P-value
Uncoated and 19 × 25 ss	0.6645 ± 0.0449	0.75	0.625	<0.001*
Coated and 19 × 25 ss	1.3394 ± 0.2496	1.68	1.104	
Uncoated and 18 ss	0.9248 ± 0.2818	1.422	0.758	0.068
Coated and 18 ss	1.2555 ± 0.2486	1.66	0.94	
Uncoated and 18 NiTi	0.9024 ± 0.1717	1.14	0.711	0.006*
Coated and 18 NiTi	1.3156 ± 0.1768	1.55	1.079	

\*p &gt; 0.05

TABLE III Results of shear bond strength test

Groups	Shear bond strength (MPa)	Min (MPa)	Max (MPa)	P-value
Uncoated brackets	21.702 ± 9.864	5.77	34.37	0.829*
Coated brackets	20.772 ± 9.127	6.67	34.98	

\*p &gt; 0.05

interaction might be possible between the bracket, and arch wire.

## Conclusion

Although silver coating with electroplating method did not affect the bond strength of the bracket to enamel, there is no effective method for decreasing friction in sliding mechanics.

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